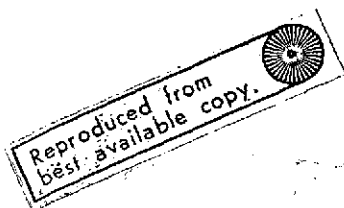


THE EFFECT OF CLOUDS ON THE IDENTIFICATION OF THE EARTH'S SURFACE
IN VISUAL OBSERVATIONS AND PHOTOGRAPHY FROM SPACE

B. V. Vinogradov, V. B. Lipatov and V. I.
Sevast'yanov

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ANNOTATION

Results of visual observations of the earth's surface by an astronaut, in the presence of sporadic clouds and shadows on the surface are presented. With the example of photographs of the Sal'sk steppes, a considerable reduction in interpretation capabilities is demonstrated in the presence of clouds and their shadows. The effect of coverage by sporadic and solid clouds models on the capability of reconstructing images of two types of targets in sections masked by clouds and their shadows is analyzed.

THE EFFECT OF CLOUDS ON THE IDENTIFICATION OF THE EARTH'S SURFACE IN VISUAL OBSERVATIONS AND PHOTOGRAPHY FROM SPACE

B. V. Vinogradov, V. B. Lipatov,
USSR astronaut V. I. Sevast'yanov

Clouds cover a considerable part of the earth's surface. However, by observation of the earth from manned orbital spacecraft in the gaps between clouds, and even on a surface covered by clouds, many geological-geographic objects are identified. Moreover, the extent of the latter, with varying degrees of probability, can be interpreted on masked areas beneath the clouds. We present some results of such observations, made by USSR astronaut V. I. Sevast'yanov during the long flight in the Soyuz-9 manned spacecraft, from 1 to 19 June 1970, and examples of geographical interpretation of photographs of the earth obtained by him.

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VISUAL OBSERVATIONS

Visual observations of geological-geographical objects of the principal types on the earth's surface were carried out, in accordance with the scientific experiment program of the flight[3]. In this article, we note only an insignificant portion of these observations, namely: the effect of cloudiness and the shadows cast by it on the ability to look at the earth's surface.

Depending on cloud type, its coverage, the sun height above the local horizon and the nature of the underlying surface, the results of visual observations in sporadic cloudiness are different.

First, with the same total coverage, sporadic cumulus clouds interfere less with interpretation of the surface than massive stratus or thick cumulus. This is explained by the possibility of interpolation of the characteristics of the underlying surface from the gaps between the clouds over sections which are under the clouds and shadowed.

* Numbers in the margin indicate pagination in the foreign text.

The principal factor determining the ability to scan the earth's surface is the extent of its coverage with clouds. Thus, with a sun height of about 45° and coverage of up to 50% of the observable territory by sporadic cumulus clouds of Cu hum. form, i. e., when the /44 gaps between the clouds are approximately equal to the cloud dimensions, satisfactory conditions for observation of the earth's surface still are maintained. The maximum cloud cover at which it apparently begins to be impossible to carry out visual observations of the earth's surface, with a sun height of over 45° , is about 75-80%. Coverage with sporadic clouds of less than 25% of the territory interferes negligibly with visual observations of natural formations.

The possibility of looking at natural objects with various degrees of foreshortening -- ahead of, to the left of, to the right of and behind the relative flight direction of the manned spacecraft -- favor observation of the earth's surface by an astronaut. As a result of this, the unobservable areas under cumulus clouds is significantly decreased. Moreover, owing to the noticeable displacement of shadows from clouds during a flight, survey of the underlying surface also is improved.

Under comparable conditions of cloud coverage and shape, the effect of the sun height on ability to examine the surface in gaps between the clouds is appreciable. As a rule, with increase in sun height, owing to a reduction in the areas of the shadows cast, ability to examine the earth's surface is improved. However, this dependence is not universal. Thus, together with an increase in sun height, the contrast of the shadows with the illuminated background of the earth's surface is increased, which decreases ability to examine details in the cloud shadows. On the other hand, with decrease in sun height, with development of a light-dark mosaic, caused by micro and mesorelief and structure of the vegetative cover, observation of many small details of the earth's surface is improved. As a result, various factors lead to the situation that, in the presence of sporadic clouds, the optimum conditions for distinguishing details on the earth's surface, hidden by the shadows cast by clouds, are observed at a sun height of $30-60^\circ$.

The possibility of interpolation of data of the intercloud gaps on the sections beneath the clouds also depends on the structure of the natural objects. Thus, linear objects -- rivers, roads, shorelines, structural faults -- are interpolated better on territories which are beneath clouds and shadowed, than the majority of soil and vegetation contours having a mosaic structure. Isometric objects, especially those commensurable with the cloud dimensions or smaller than them, are observed considerably more poorly (plowed fields, cities, settlements, small lakes).

Finally, it was determined that various natural formations within the shadows cast by clouds are examined better by an astronaut than they are recorded on panchromatic space photographs. This is explained by a number of factors. Objects in shadows, illuminated by scattered light, are distinguished better by an eye sensitive to the shortwave portion of the visible band of the spectrum and having maximum sensitivity in the green portion of the spectrum. On panchromatic photographs, this band of the spectrum is eliminated to a considerable extent by the yellow light filter, and the maximum sensitivity of the photographic film is in the orange-red portion of the spectrum, in which details in shadows are almost not distinguished.

From our observations, within the shadows cast by clouds, various natural objects are identified. In observations of agricultural lands, principally fields, their boundaries and the rectangular structure are distinguished. An astronaut distinguishes fields with ripe (yellowish-grey color) and harvested (lightish grey tone) agricultural crops from green crops (dark green) and plowed fields (black, dark brownish, dark brown and even dark violet color, corresponding to the color of the soil and soil-forming rock).

Rivers and river valleys are scanned within cloud shadows. Dark 45 green oases are identified on a background of yellow-grey and brownish-grey desert territory. The colors of water masses are distinguished;

however, they change under the influence of superimposed shadows. Thus, in South America, rivers with reddish and dark grey toned water were observed simultaneously and, under cloud shadows, their colors changed to brownish and black, respectively.

The boundaries of forest-covered and treeless territory are traced in shadows. Some classes of forest formations are identified (for example, coniferous and deciduous, moisture-seeking tropical forests and light-seeking ones). Some forests are distinguished well by thickness, for example, in a savanna, by hues from dark green to brownish grey.

Ocean shorelines, as a rule, are easily scanned and interpolated. In this case, clouds sometimes even emphasize their direction, due to the contact of different convection conditions above the land and above the sea. Large waves are noticeable on the surface of sea under shadows, especially storm waves with crests and foam and the wakes behind large ships.

Some geological formations, especially linear and circular ones, also are traced and interpolated in shadows. Several lithological types of the underlying surface are distinguished: clayey, sandy and rocky.

Finally, objects of the cultural landscape are easily examined in shadows: major highways and cities with a grid of streets.

PHOTOGRAPHY

Photography was carried out from the Soyuz-9 manned spacecraft on panchrome film under a yellow light filter, with a small hand camera, having 6 x 6 cm frame size [2]. A photograph (Photo 6) gives an image of the landscape of the dry steppes of the Sal'sk key section, partially covered with sporadic cumulus and cumulonimbus clouds. The photograph was taken on 15 June 1970, from an altitude of 228.4 km,

at 17 hours 41 min 05 sec Moscow time, on panchrome film, at an original scale at the subsatellite point of about 1:7,560,000, with an angle of inclination of the optical axis of 9.2° and a photographic azimuth of 303° . At the time the photo was made, the sun height was about 21° above the local horizon and the illumination azimuth was about 245° .

The coordinates of the subsatellite point, determined by the Aero-methods Laboratory, Ministry of Geology, USSR, were: $\lambda = 43^\circ 30'$ and $\phi = 46^\circ 45'$. The calculated resolution on the photograph, based on a scale of the original of about 7,560,000 and a resolving power of 0.035 mm, is 264.6 m. The smallest resolved element, measured by identification of details of the earth's surface on the photo (excluding high-contrast linear objects: canals, roads) is 200-300 m. The majority of fields have dimensions of 0.5-2 km on a side and, consequently, with sufficient optical contrast, they give a differentiated image. A large portion of the cumulus clouds have dimensions of about 1-2 km and more and, consequently, they give completely clear images on a space photo. Interpretation was carried out from a print, enlarged 12.5 times, to a scale of about 1:600,000.

The territory of one of the principal key sections (Tsimlyansk-Sal'sk) for study of natural resources by aerial photographic means, is depicted in the photograph (Photo 6). The section is located in the upper part of the Sal river, on the Dzhurak-Sal and Kara-Sal watershed boundaries. The terrain is sloping-rolling plains with markers about 100 m above sea level. The region is composed of horizontal Pleistocene, loamy, forested deposits on the surface. The soils on the water divides /46 are chestnut brown and alkaline chestnut brown, and meadow-chestnut brown, with a larger portion alkaline, in the valleys. A considerable portion of the territory is occupied by agricultural crops (mainly wheat). The virgin vegetation is wormwood-fescue-(feather grass) in dry steppes. The following elements are identified on the space photograph (Fig. 2): clouds (area 24%), shadows cast by clouds (area 20%), freshly plowed fields, fallow fields, cultivated crops, winter plantings

(area 23%), mature crops, stubble (area 2%), virgin soil, wastelands, undifferentiated plantings (31% of the area).

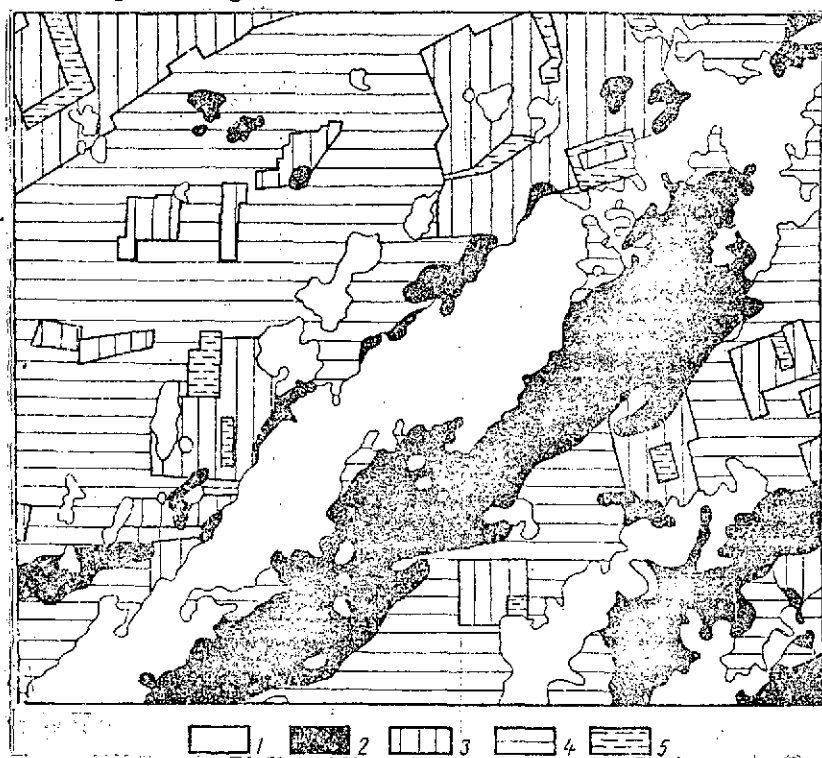


Fig. 1. Fragment of interpretation diagram of space photo of Sal'sk steppes (see Photo 6): 1. clouds; 2. cloud shadows; 3. agricultural crops in vegetative stage and plowed fields; 4. Virgin land, wasteland, undifferentiated crops; 5. mature and harvested crops.

Clouds. On a fragment of the space photo, clouds are seen, in the form of a bank of cumulus and thick cumulus forms, extending along the direction of the west wind. The cloud banks have broken, locally diffuse boundaries. The width of the large banks is 6-8 km, and of the narrower ones, 2-4 km. The edges of the clouds are thinner; in places they approximate the tone of the image of the earth's surface in tone density, fusing with it and masking it. The vertical structure of the cloud banks can be judged by the width of the cloud band and by the increase in image brightness. Moreover, on the narrow, shadowed side of the clouds, the shadows proper are noticeable on the clouds. The shadowed sides of the cloud banks fuse locally in tone density with the image of the earth's surface. Such a type of cumulus cloud banks is connected with the development of strong convection.

An analysis of the synoptic situation showed that a diffuse front /47
passed through this region at this time, which gave an impetus to the formation of cumulus and cumulonimbus clouds, which then combined and stretched out in the form of a bank along the line of the front. In fact, rare torrential rains occurred in this region, including some with thunderstorms.

Beside the principal cloud banks, individual good weather cumulus clouds are seen on the photograph, in the form of isometric light spots with diffuse edges. These unorganized cumulus clouds have horizontal dimensions of 1-3 km, and they are distributed more or less at random. The formation of individual cumulus clouds also is connected with thermal irregularities of the surface. Above the hotter plowed fields, with colder sections in the vicinity, ascending currents formed and, at the altitude of the condensation level, cumulus clouds formed. The wind deflected these ascending currents; therefore, the position of the clouds formed does not always coincide with the location of the hotter sections of the plowed fields.

Cloud shadows. The shadows on the photograph have good directionality along the solar illumination azimuth line, and they are depicted in dark tones. The shadows of individual clouds duplicate the dimensions of the latter and are removed from their illuminated base in the direction of the azimuth of the sun by 5-6 km. The shadows of the tops of the cloud banks are considerably more distant in places, up to 12 km, which is connected with the fact that individual sections of the banks have considerable thickness. The densities of the cloud shadows change, depending on cloud thickness and size: the denser ones (dark tones) are below large cumulonimbus clouds and the less dense ones (darkish grey tone) are below the filamentous frameworks of unorganized cloudiness. In low-density cloud shadows, the contours of objects with the greatest contrast are seen from time to time: meadows and freshly plowed fields, on the background of drying wild vegetation.

Freshly plowed fields. After the early harvest of winter wheat and fodder grass, some fields were newly plowed. Freshly plowed chestnut brown soils give the lowest intensity factor (in the photoactinic region of panchromatic photographic film $r = 0.08-0.14$), and their brightness is comparable to the lowest brightnesses of dense shadows cast by clouds. Their tones are represented on the photo by dark and dark-grey, fusing with the cloud shadows. Plowed fields, however, differ from the latter by their rectangular configuration, with sharp boundaries. The brightness factor increases to $0.12-0.18$, in proportion to drying out of the chestnut brown soils, and the tones of their images change to darkish grey.

Cultivated plantings and summer crops, fallow fields. Eight different agricultural areas, which are close together in brightness factor ($r = 0.16-0.18$), are combined by image tone (dark grey, darkish grey) in this group: spring fallow fields, cultivated crops (corn, tobacco, sunflower, sudan grass) and also green plantings of summer grain crops (barley, oats), ripening 10-15 days later than the winter ones.

Grain crops. Plantings of winter wheat, predominating in the planted areas of the region, were in the milk-wax stage of ripeness. They were represented predominantly by a darkish grey tone, corresponding to a brightness factor of $0.18-0.22$.

Virgin soil, wasteland, fallow fields. The previous year's fallow fields, overgrown with annuals and biennials, wastelands, wild vegetation with predominantly wormwood-fescue associations, drying out and turning yellow everywhere in this season, give low-contrast images of predominantly grey and lightish grey tones. Agricultural crops of this category occupy only a third of the area of the section, and they are characterized by the smallest number of identifiable details.

Mature crops and harvested fields. Mature wheat and annual grass plantings give the highest brightness factor among the other ground objects, reaching $r \approx 0.25-0.30$. They occupy small areas, and they are represented in the photo by a lightish grey tone, sometimes fusing with the shadowed sides of the clouds.

RECONSTRUCTION OF THE IMAGE OF THE EARTH'S SURFACE MASKED BY CLOUDS AND THEIR SHADOWS

Some landscape elements, identified in the illuminated gaps between the clouds, can be interpolated in the territory masked by clouds and their shadows. For determination of the likelihood of interpolation of such data on masked territory, we analyzed empirical models of clouds and shadows (masks), on the one hand, and images of the underlying surface (targets), on the other. Two types of targets and nine gradations of coverage by masks, from 10 to 90%, were used.

In modeling sporadic (cumulus) clouds, the shape of each individual cloud and its shadow was approximated, in the form of a circle. Its size was equal to 1% of the area of the target. Thus, with a 100 cm^2 diameter target, each mask amounted to about 11 mm. In modeling solid (stratus) clouds, the masking models approached a single circle in shape, the area of which also changed from 10 to 90% of the target area.

Two targets were then chosen on the earth's surface, with different types of images. The first target was an image of the geological structure of the broken brachyanticlinal structure of the southern region of the Zagros Highlands, studied from a photograph (Fig. 2a). The second target was a simple, parallel straight-line figure, simulating structural fracturing (Fig. 2b).

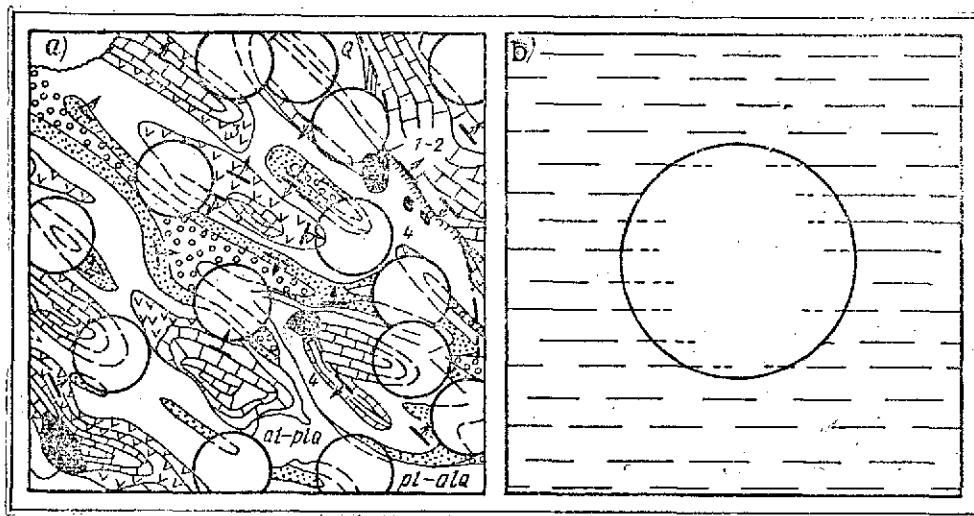


Fig. 2. a. Sample target with closed elliptical structure of broken geological folds, with 20% coverage by modeled sporadic clouds; the broken lines in the circles are interpolated stripes of stratigraphic contacts in the masked sections; b. sample target with linear structure of geological faults, with 20% coverage by modeled solid cloudiness; broken lines are interpolated geological fault strikes in the masked sections.

Cloud and shadow masks were superimposed on both targets. /49

The location of each sporadic cloud mask was selected by means of a table of random numbers, and the solid cloud masks were fixed in the center of the target. After this, the operator interpolated the results of interpretations from the open territories to the masked ones for each mask coverage gradation, beginning with the maximum (90%) and ending with the minimum (10%). The operator carrying out the interpolation was the experienced specialist in structural geology G. A. Putintseva, who, however, was not familiar with either the geological structure of the region or with space photographs. Control of the interpolation was accomplished from the data of the geologist V. A. Sumarokova, who had previously analyzed the space photos and data of the geological structure of the region in all details.

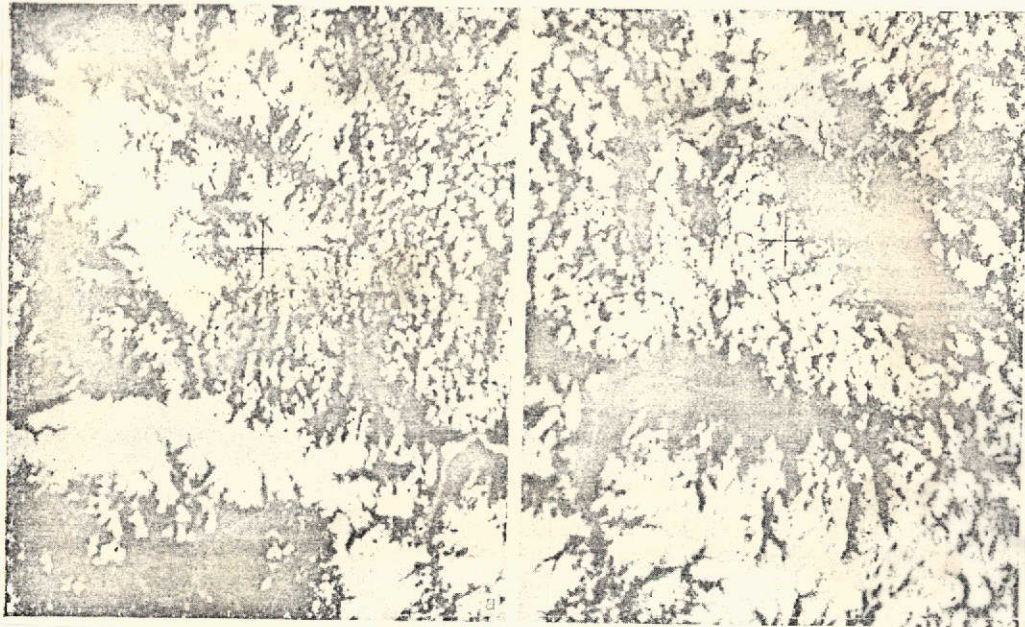


Photo 1. Photos of clouds taken 14 June 1971.

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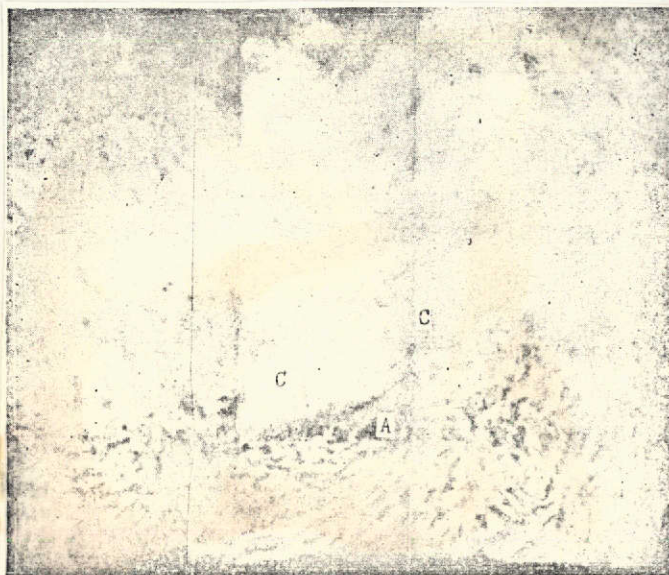


Photo 2. Photomontage of pictures taken 11 June 1971.

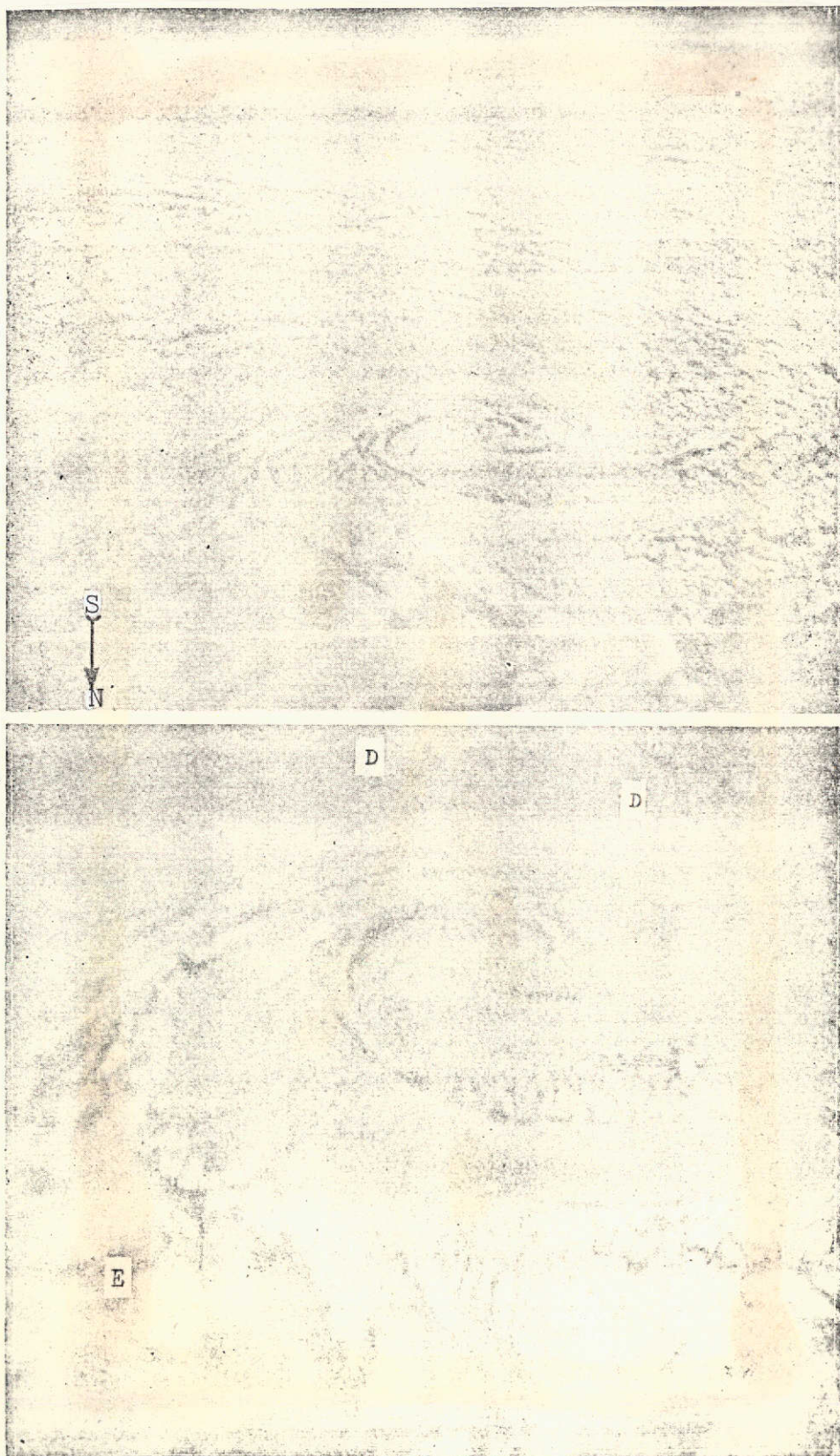


Photo 3. Low pressure area cloudiness over
Indian Ocean on 27 June

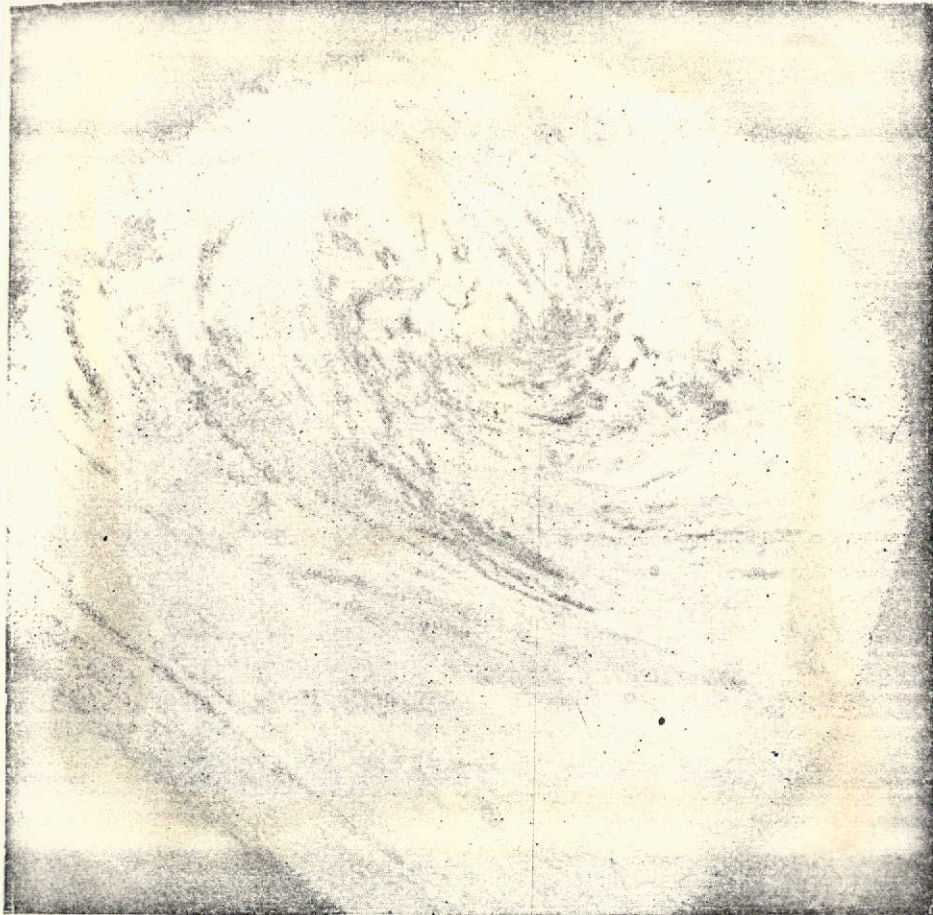


Photo 4. Cloudiness of occluded low pressure area over Indian Ocean on 27 June.

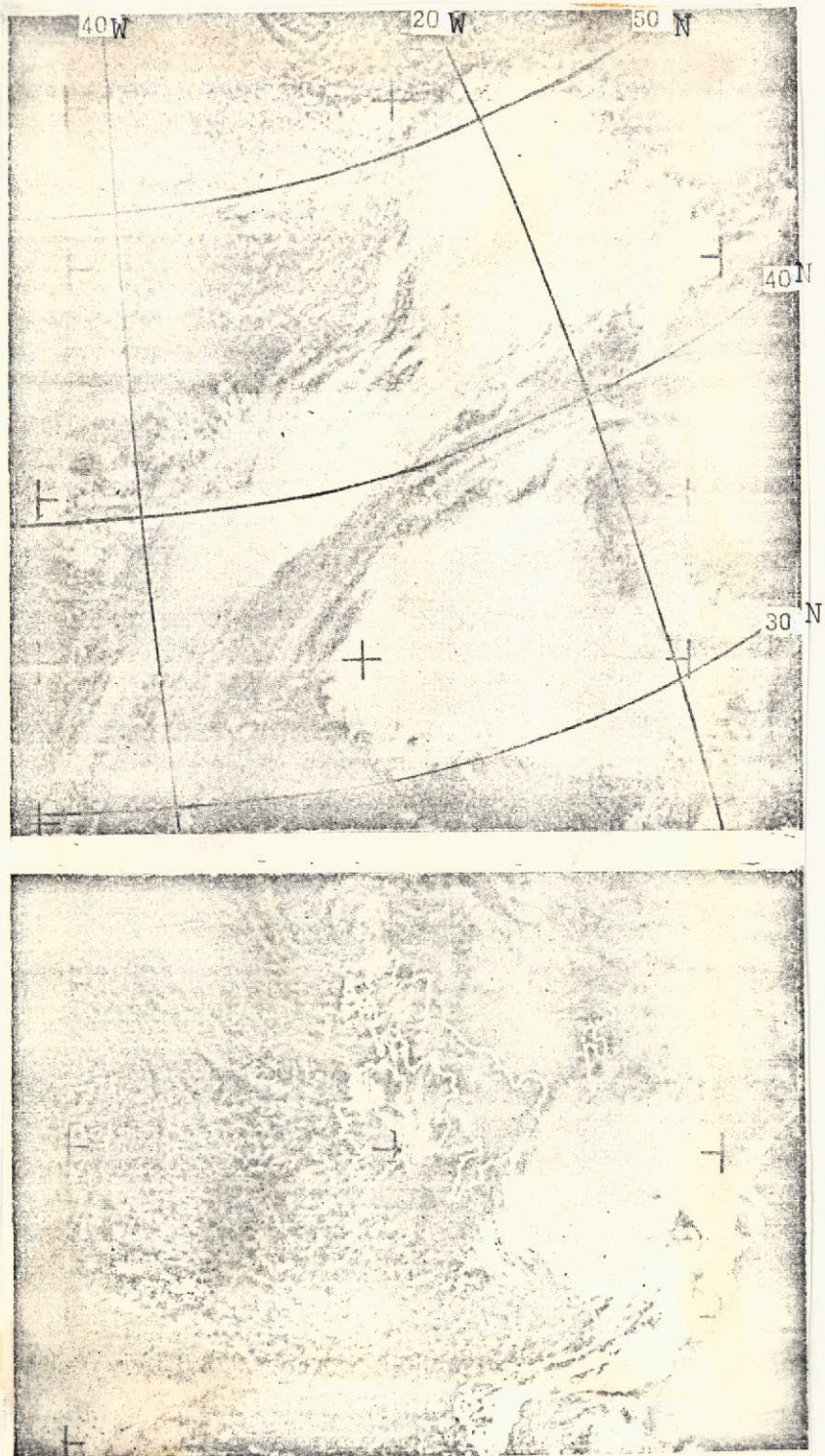


Photo 5. Cloud situation 12 (upper) and 13 (lower)
February 1972, ESSA-8, orbit 14,485, 12 hours
28 min, orbit 14,497, 11 hours 24 min.

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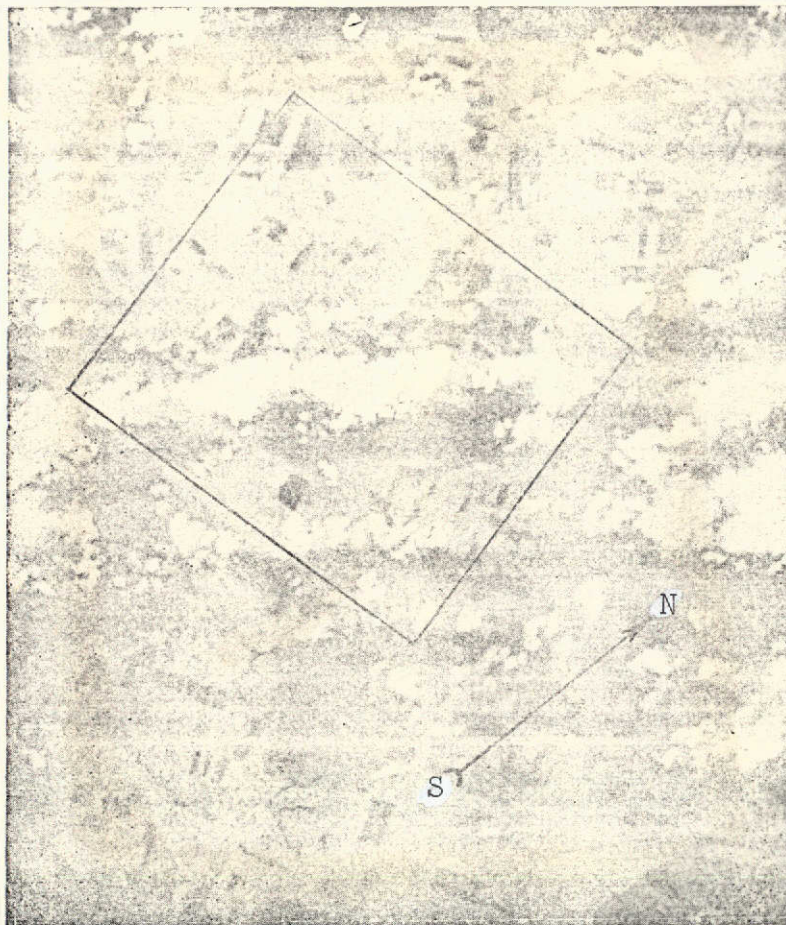


Photo 6. Fragment of space photo of Sal'sk Steppes from Soyuz-9 manned spacecraft 15 June 1970, at original scale 1:7,560,000, with sun height 21° .

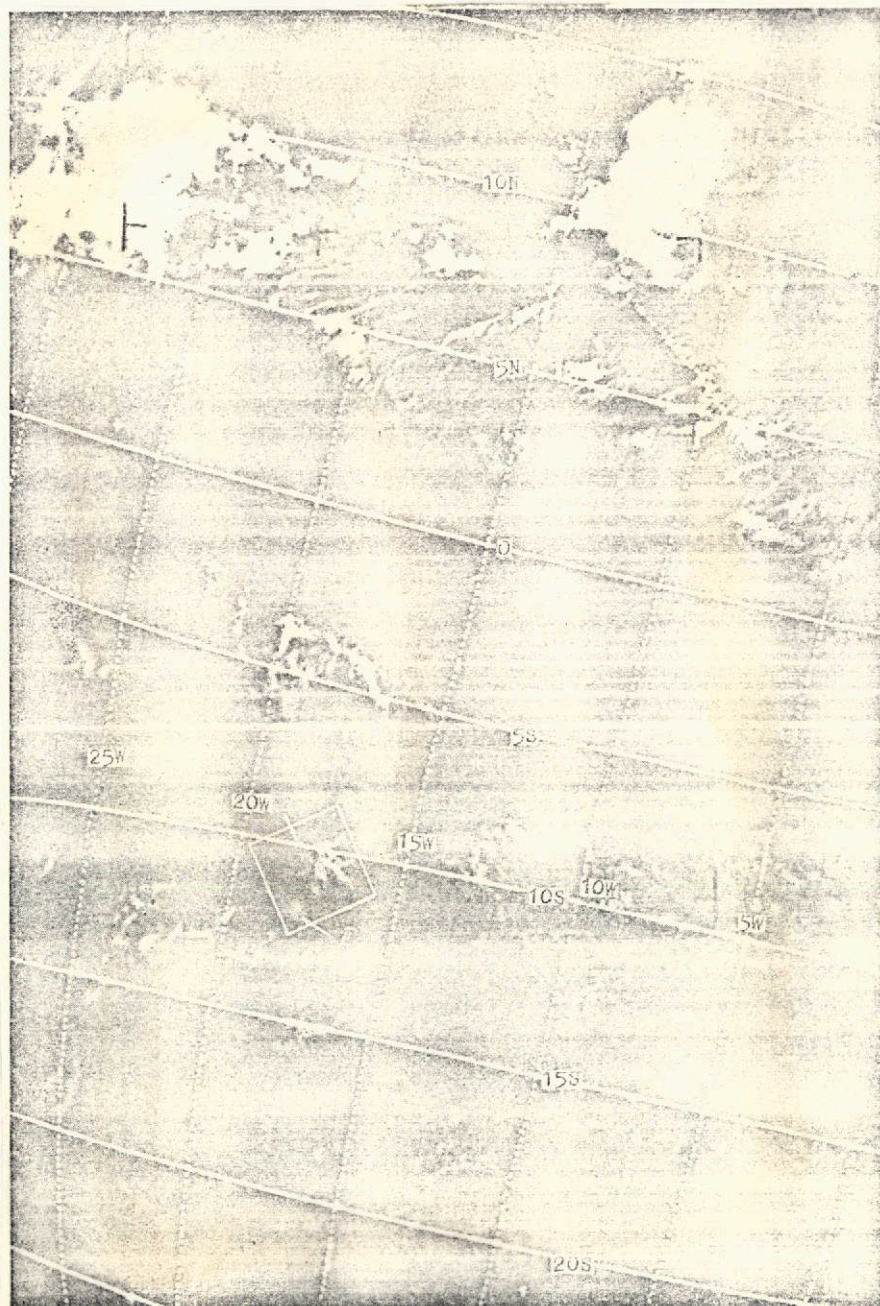


Photo 7. Cloud situation at 15 hours 26-31 min over tropical latitudes of Atlantic Ocean, from data of ESSA-9 meteorological satellite 15 June 1970.

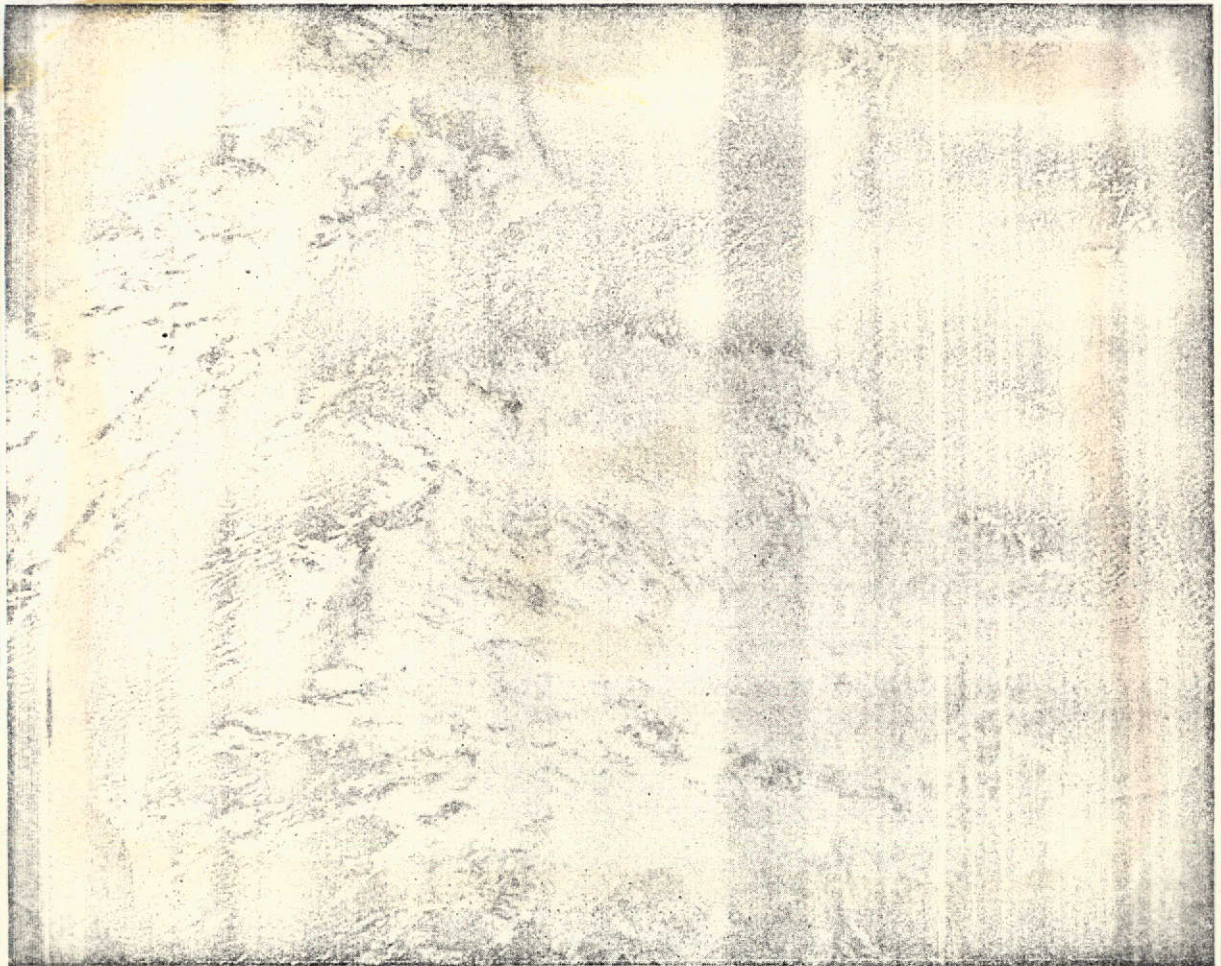


Photo 8. Cloud accumulation in South Atlantic tropics;
photo taken from Soyuz -9 spacecraft 15 June 1970 at
14 hours 20 min.



Photo 9. Perspective photo of thick storm cloud, taken from Soyuz-9 spacecraft; the cloud casts a long shadow, since the photo is an evening one.

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After the interpolation and control of nine models of mask coverage (from 10 to 90%) on the two targets with the two cloud forms, the total length of the line of the geological structure image (brachy-anticlinal structures and discontinuous dislocations), both in the open sections between clouds and correctly interpolated in the masked sections (L_0) and the length of the line of the figure of erroneously interpolated or omitted ones (L_Δ) were measured. This permitted the relative error in reconstruction of the image of the earth's surface masked by clouds and shadows of different coverages $\Delta = L_0/L_\Delta$ (Fig. 3) to be calculated. Graphs of the errors in the reconstructed image of the surface masked by clouds and shadows vs. mask coverage were plotted from these data.

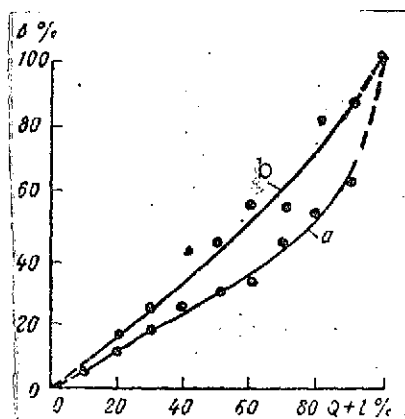


Fig. 3. Forms of relations between model cloud coverage (sporadic cumulus, a, and solid stratus, b) and shadows cast by it ($Q + 2\%$) and errors in reconstruction of masked image of geological structure ($\Delta\%$).

From an analysis of the graphs obtained, it is evident that the errors in reconstruction of the masked image of the linear structures is less than in mosaic ones. For example, with 50% mask coverage, the reconstruction error of closed mosaic images is 1.4 times greater than the reconstruction error of linear images. In both cases, the image reconstruction error initially increases linearly and then, beginning with a mask coverage (i.e., of clouds and shadows) of about 60%, the errors begin to increase more rapidly.

The results of the model analysis also indicate that solid cloudiness interferes more with interpretation of the earth's surface than sporadic clouds. With surface targets having linear figures and solid (stratus) clouds, the reconstruction error is 1.5 time greater than the

reconstruction error of the same image, when masked with sporadic (cumulus) clouds.

CONCLUSION

We compare the ability to inspect the earth's surface in the Sal'sk key section, covered with clouds and shadows, from the interpretation data of space photographs from the Soyuz-9 manned spacecraft and the empirical model of cloud and shadow masking of details of the earth's surface described above, as well as based on calculation of the additional coverage with cloud shadows by an analytical formula [1].

The cloud cover measured on the photograph (Fig. 1) was 24%, cloud shadow coverage was 20% and ability to inspect the surface was 56%. 450

We calculate the additional coverage by cloud shadows from a formula describing the relation between cloud cover, sun height above the local horizon and the probability of coverage of the earth's surface with cloud shadows [1]. Based on coverage by sporadic cumulus clouds of 24% and a sun height of 21%, we obtained a calculated shadow coverage of 18%. As is evident, our results were somewhat less than the empirical (by 2%). This apparently is explained by the fact that the semitransparent cloud margins are poorly identified on the photograph and are not allowed for in the calculation, but the shadows they cast are noticeable and mask details of the earth's surface.

Further, we compare the measured coverage of the territory (44%) by cumulus clouds (24%) and shadows (20%) with the empirical value of the error in interpolation of data onto the territory beneath the clouds with the same masking dimensions (44%) within targets. The image reconstruction error determined from the graph (Fig. 3) proved to be 33%, which is 11% less than the cloud and shadow coverage. As a result, under the conditions described above, photography of about

a fourth of the outlines could be interpolated onto the territory beneath the clouds, with a 95% probability.

In this manner, clouds and cloud shadows, even with a low degree of cloudiness, at a low sun height, sharply reduces the ability to examine territory on a photograph. The number of successive photos of a territory (N) with random dates, under such photography conditions, to obtain even a single image of the entire surface with a probability of successful photography of the surface $P_{(M)} = 0.95$, can be calculated from the formula

$$P_{(Q+l)}^N < 1 - P_{(M)} \quad |$$

where $P_{(Q+l)}$ is the area of the surface covered with clouds and shadows. In our example, this corresponds to the inequality $0.44^N < 1 - 0.95$, from which it follows that $N > 3$. As a result, with cloud and shadow coverage of 44% under similar illumination conditions, to obtain an image of the entire territory with the probability of 0.95, the key section must be photographed at least four times.

Thus, the data presented are evidence of the very complex effect of cloudiness on identification of the earth's surface. Broken, sporadic clouds interfere with visual observation of the earth's surface less than with photographs of it. However, there are various relations between cloud type and coverage and the sun height, structure of the underlying surface and its optical contrasts and experience of the observer and interpreter. Finally, there is a definite, although limited, possibility of interpolation of data onto territory masked by clouds and shadows.

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Abstract

The results of visual observations of the earth's surface by an astronaut, with sporadic cloudiness and shadowing of the surface, are presented. With the example of photography of the Sal'sk steppes, a considerable reduction in the possibilities of interpretation, in the presence of clouds and their shadows, is demonstrated. The effect of coverage by sporadic and solid model cloudiness on the capability of reconstructing images of two types of targets, in sections masked by clouds and their shadows is analyzed. It was found that, with 44% cloud and shadow coverage a key section must be photographed at least $\frac{1}{10}$ to obtain an image of the entire territory with a 0.95 probability. It also was found that there is a limited capability of interpolation of data onto territory masked by clouds and shadows.